

**Before the  
Federal Communications Commission  
Washington, D.C. 20554**

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**In the Matter of**

**Revision of Part 15 of the  
Commission's Rules Regarding  
Ultra-Wideband Transmission  
Systems**

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**ET Docket No. 98-153**

**COMMENTS OF MOTOROLA, INC.**

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## SUMMARY

The Commission has proposed a variety of rules to govern the development and implementation of UWB technologies. The unique technical feature of UWB is that its transmissions span broad bandwidths that include frequencies used for public safety, such as fire and police; aircraft landing systems; GPS; military systems; broadcast communications; cellular communications; satellite systems; and other specialized networks. In its *NPRM*, therefore, the Commission has proceeded with appropriate caution, recognizing that UWB devices present a potential to cause harm to these other wireless technologies and services. In addition, UWB devices have the potential to affect systems that are not yet operational, limiting the evolution of communication technology generally in the United States. For these reasons, it is necessary that the potential impact of UWB signals on other radio systems be examined critically.

In order to assess UWB's interference potential, Motorola has analyzed UWB transmissions in a variety of typical radio environments. Several methods of assessing interference potential were considered, and the likely effects on generic receivers were carefully examined. Based on these detailed analyses, Motorola concludes that the Commission's tentative decision to require that UWB emissions below 2 GHz be attenuated by at least 12 dB below the general Part 15 emission limits is both appropriate and necessary. In addition, Motorola's analyses show that the same protection level is warranted for UWB devices operated above 2 GHz. This 12 dB reduction strikes a reasonable balance between protecting existing and future radio services and encouraging technological innovation.

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To the Commission:

**COMMENTS OF MOTOROLA, INC.**

Pursuant to Section 1.415 of the Commission's Rules, 47 C.F.R. § 1.415, Motorola, Inc. ("Motorola") hereby submits its comments in the above-captioned proceeding.<sup>1</sup> Based on its detailed analysis, Motorola believes that ultra-wideband ("UWB") technology as proposed in this proceeding can cause a significant increase in the noise floor for other communications services. Motorola therefore urges that the Commission set the UWB emissions limit at least 12 dB below the current Part 15 Class B limits for all frequencies, both above and below 2 GHz.

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<sup>1</sup> *In the Matter of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, ET Docket No. 98-153, Notice of Proposed Rulemaking, 65 Fed. Reg. 37332 (June 14, 2000) ("*NPRM*").

## **I. INTRODUCTION**

Motorola is pleased to offer these comments in the Commission's proceeding on UWB technologies. Motorola believes that these technologies are promising for certain applications such as location sensing and short range communications. However, UWB must be carefully evaluated by the Commission to ensure that it can co-exist with other wireless technologies and services.

First, rules developed to accommodate UWB must take into consideration its unique features and spectrum signature. While most other communication systems are designed to limit their transmissions to a band specifically assigned for their use, UWB transmits on a broad range of frequencies already assigned to other communication systems. Indeed, because UWB transmissions can span frequencies from hundreds of kilohertz to many gigahertz, they have the potential to interfere with virtually all existing communication systems. These include communication systems utilized for public safety such as fire and police, aircraft landing systems, GPS, military systems, broadcast communication, cellular communications and satellite systems, as well as other systems used for more specialized but important applications. Beyond the impact to systems currently in use, UWB also has the potential to affect future communications systems and thereby limit the evolution of communications technologies. Given the growing importance of wireless communications systems and the frequencies they use, any potential for UWB interference must be critically examined.

The bandwidth used by UWB, however, does not necessarily mean that it will cause interference. The UWB transmit power level, and the proximity of a UWB transmitter to another system's receiver, are relevant factors. Thus, how and where UWB

devices will be used is equally important in determining the potential for interference. For example, a proposal for a UWB-based air interface has been made to the IEEE P802.15 working group for personal area networks.<sup>2</sup> As the name implies, these networks are short-range wireless systems carried by individuals. They are used in highly mobile, ubiquitous environments – wherever there are people. In these environments, it can be expected that UWB transmitters will be in close proximity to other personal communications devices such as cell phones, personal entertainment receivers and GPS receivers as well as future communications receivers.

For these reasons, UWB transmissions must be carefully analyzed, and any Commission rules must be written to prevent interference to current services and future technologies. To this end, Motorola will address the critically important first step of assessing potential interference from UWB: the proper method for assessing the interference risk from UWB devices into non-UWB wireless communications systems.

## **II. THERE ARE SEVERAL METHODS OF ASSESSING INTERFERENCE POTENTIAL**

When assessing the impact that a UWB transmitter would have on other wireless devices, there are a number of approaches that can be taken. These include evaluating the impact of interference on a generic receiver, evaluating its impact on a specific type of receiver or evaluating its impact on a receiver in a specific system.

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<sup>2</sup> Document IEEE 802.15-00/082r1.

- **The Effect On a Generic Receiver**

In this type of analysis, the victim receiver is described by a few quantities relevant to a range of receivers, specifically antenna gain and a noise figure. Details of the specific receiver are not needed.

- **The Effect On a Specific Receiver**

Here, a number of details of the victim receiver are needed. These would include, for example, the specific modulation scheme used, gains achieved by coding or spreading, the desired-to-undesired signal ratio and potentially a number of other factors. For every type of receiver that might be interfered with, specific details are required.

- **The Effect On a Specific System**

In this analysis, further details of the system design would be included to determine the impact of the UWB interference. For example, in a typical CDMA system, power control and various types of soft handoff are used to mitigate interference from the system into itself. These techniques will have some impact on the ability of the system, and elements of the system, to operate in the presence of UWB interference. It might also be necessary to determine the minimum allowable carrier-to-interference ratio for the system and the carrier-to-interference distribution over a coverage area. For every type of system that might be interfered with, a significant amount of detail about the system is required.

- **Field Tests Are Very Valuable, But the Results Must Be Analyzed With Care**

While field tests can provide an enormous wealth of valuable data, the results of these tests must be analyzed with care. A simple test may show, for example,

that when presented with a noise source at the Commission's Part 15 limit, the victim receiver does not experience any noticeable interference. However, under different operational conditions, the interference can be harmful.

This is one of the complications of including the specific system information into the interference analysis. Land mobile systems, for example, have been designed with margins to maintain link quality in the face of effects such as Rayleigh fading and log-normal shadowing. This is reflected in the fact that the "static sensitivity" of a receiver (*i.e.*, its sensitivity when standing still) can be as much as 10 dB lower than the "faded sensitivity" (*i.e.*, its sensitivity when in motion).<sup>3</sup> The system may continue to perform well in the face of UWB interference, but at the expense of reduced limit margin. This reduction in margin may not be noticeable in a static case, but would be very noticeable in the faded case.

In another example, interference caused by a UWB device may be measured in a cellular system in an area of moderate cellular signal strength and see no degradation in performance. However, if a measurement is made at the edge of coverage or inside a building, the interference may introduce significant interference or cause a call to drop.

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<sup>3</sup> Hess, Garry C., Land-Mobile Radio System Engineering, Boston, Artech House, 1993, p. 13.

### **III. THE EFFECT OF UWB DEVICES ON A GENERIC RECEIVER IS THE BEST APPROACH FOR ASSESSING INTERFERENCE**

A review of the work of the FCC's Technology Advisory Committee Spectrum Management Working Group<sup>4</sup> (Noise Subcommittee) ("FCC TAC") indicates that the generic receiver approach to the problem of UWB interference can simplify the analysis and also provide models that ensure that current and future communications systems will not be significantly impaired. The approach proposed by the FCC TAC examines "critical-use scenarios" and evaluates the noise floor rise in those scenarios. Because all communications systems are ultimately limited by the noise floor, if the impact on the noise floor of the receiver is minimal the interference level can be deemed acceptable without resolving the detailed characteristics of the receiver or the associated system. If likely future scenarios are incorporated, this approach also can be used to avoid major impacts on future communications systems. Other advantages of this approach are discussed below.

#### **A. Results On a Generic Receiver Can Be Applied As a Baseline to All Other Systems**

Any analysis of interference must begin with an examination of the increase to the noise floor caused by the interference source. Other details of the specific receiver or system design may mitigate these effects, but the generic receiver analysis is the most straightforward method to use.

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<sup>4</sup> <http://www.jacksons.net/tac/>

**B. Modeling Specific Receivers and Systems Introduces Too Many Independent and Uncontrollable Variables**

In many cases of interference management, it is possible for commenters and the Commission to include detailed information about the victim receivers and systems in the analysis, and to make conclusions based on these specific circumstances. In this proceeding, however, such an effort would be unmanageable. Previous commenters in this proceeding have explained that UWB devices will operate with a center frequency anywhere between 20 MHz and 60 GHz, with bandwidths ranging from 150 MHz to 30 GHz.<sup>5</sup>

The victim receivers and systems could, therefore, be virtually anywhere across the electromagnetic spectrum. It is not an exaggeration to say, therefore, that any attempt to examine specific systems and implementations would require a look at all wireless communications systems in operation today.

The differences among systems are enormous. Systems can be fixed, mobile, or satellite. Even among land mobile communications systems, there are significant differences between systems. They differ in how they

- use power control
- use data retransmission
- incorporate link margin into the system design.

Many more areas of difference exist. It would be unrealistic to expect any analysis to account for all of these differences.

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<sup>5</sup> See, e.g., Comments of Lawrence Livermore National Laboratories at 3.

Therefore, while it might be desirable to look at the interference potential on specific systems, the generic receiver approach can give results that can be easily applied to a wide range of systems.

#### **IV. GENERIC RECEIVER METHODOLOGY**

In this section Motorola presents an analysis based on the generic receiver method. As will be shown, UWB devices with Part 15 emission levels will cause unacceptable degradation of the receiver noise floor at distances of 13 meters or more to many mobile communications systems. Further analysis shows, however, that a reduction of the UWB emission levels can virtually eliminate this problem.

In the cases Motorola has examined, the interference from a UWB transmitter into a victim receiver can be accurately modeled as Gaussian noise.<sup>6</sup> Therefore, in the models discussed below, interference from a generic UWB transmitter is analyzed in terms of its ability to increase the noise floor of the victim receiver.

It should also be noted that UWB transmitters may be operated in a TDMA mode. Depending on burst duration, pulse shaping and frame rates, UWB transmitters operating in this mode may cause harmful interference comparable to the interference generated by a continuously transmitting UWB device, *i.e.*, the cases analyzed herein. Indeed, in some cases the impact of the interference from pulsed UWB

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<sup>6</sup> "If the interval between UWB pulses varies randomly, the interference appears to be broadband noise with an average power that varies as the average pulse rate multiplied by the receiver bandwidth, as long as the average pulse rate is much greater than the receiver bandwidth." *See* Comments of the Wireless Information Networks Forum to the Commission's Notice of Inquiry in ET Docket No. 98-153, 63 Fed. Reg. 50184, September 21, 1998, ("NOI") at ¶7.

devices could be significantly worse than from continuously transmitting UWB devices. In this and the following sections, we assume that the power level during UWB pulse transmissions (*i.e.*, during transmitter “on” times in the TDMA mode) is the same as the power level of a continuously transmitting UWB device; thus, the UWB signal power is averaged only over the “on” portion of the transmission and not over any period of time when the TDMA UWB transmitter is off.

#### **A. Usage Scenarios**

To analyze the impact of UWB devices on a generic receiver, certain assumptions must be made. Those assumptions include:

- The density of deployment of UWB devices
- The UWB service application

These parameters should be chosen to provide a rigorous but fair test of the potential for interference. There are several likely typical scenarios. First and probably the most important is the case of a person carrying a UWB device in close proximity to a person with another personal communications device. This other personal communication device could be a standard cell phone or a cell phone with an integrated location device (GPS receiver), a Local Area Network receiver or a different PAN receiver. In this kind of situation, the UWB transmitter could be in close proximity to one of these other types of receivers with a physical separation between transmitter and receiver of as little as 1 meter.<sup>7</sup>

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<sup>7</sup> Such a small physical separation would occur if the UWB unit and the victim unit were both in the possession of the same user, or in a very high density situation, such as a crowd. For a discussion of more typical population densities, *see* n.17, *infra*.

Another scenario involves the noise increase in a base site receiver due to nearby UWB emissions. While the close physical separations of the previous case are typically not possible, base sites have significantly higher antenna gains and are located on towers. They can therefore be equally susceptible to UWB transmissions.

In both of these cases, an important consideration is the impact of multiple UWB devices, each adding to the noise level in receiver input. However, it is expected that the UWB devices closest to the receiver would dominate due to typical path loss exponents between two and four.<sup>8</sup>

In order to define the permissible level of UWB transmissions, several other parameters must also be established. These are the noise figure of the receiver, the antenna gains in use and the allowable noise increase. The antenna gains will vary depending on the specific situation. Noise figures will also vary somewhat, with typical values being on the order of 5-10 dB. It would be desirable to minimize the noise increase so that in the worst case scenario it is no more than about 1 dB.<sup>9</sup>

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<sup>8</sup> Jakes, William C., Jr., *Microwave Mobile Communications*, New York, John Wiley & Sons, 1974, *see especially* Chapter 2.

<sup>9</sup> In its Comments in the *NOI*, Arthur D. Little, Inc. proposed a model which concluded that for radio users at street level the receiver noise floor may be degraded by up to 6 dB from the thermal noise floor. It explained that “this effect is minor when compared with the known effects of poor propagation for phones due to buildings, tunnels, etc.” *See* Arthur D. Little Reply Comments at 9. Unfortunately, this conclusion fails to consider several important factors. First, communication systems are deployed with a certain signal strength margin designed to cope with common propagation effects. Any degradation of the noise floor will decrease the ability of the system to maintain its intended coverage when the propagation effects occur. Second, the areas which will be most affected by any increase in the noise floor will be those that are the most costly to cover and have the least margin available. Public safety agencies and commercial carriers deploy additional infrastructure, at considerable expense, in order to assure service in those areas. Third, integrated GPS receivers are now being deployed in cellular phones to comply with E911 location determination requirements. They have

Beginning in Section V, analyses of several of the above scenarios are presented. Based on these scenarios, an allowable level of UWB spectral emissions is proposed.

## **V. ANALYSES OF THE EFFECTS OF INTERFERENCE ON A GENERIC RECEIVER**

Motorola's analysis, relying on the generic receiver method outlined above, demonstrates that the extent to which UWB transmissions at levels currently specified in Part 15 can degrade the noise floor of both victim mobile and base station receivers, and that reducing permissible emissions by 12 dB below the Part 15 limits is necessary to protect these receivers.

### **A. Link Budget Analysis<sup>10</sup>**

The interference scenarios of interest are of the following types:

- UWB transmitters into victim mobile receivers
- UWB transmitters into victim base receivers

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virtually no spare margin and will not be capable of fulfilling their geolocation obligation where the noise floor increases by more than about 1 dB. For these reasons, the more appropriate and justifiable limit to increased noise floor degradation is 1 dB. This figure represents the maximum degradation that will permit continued viability of public safety and other mobile commercial services in the United States.

<sup>10</sup> This analysis is identical in form to the analysis conducted by the National Telecommunications and Information Administration in the 700 MHz proceeding. *See Service Rules for the 746-794 MHz Bands, and Revision to Part 27 of the Commission's Rules*, WT Docket No. 99-168, Notice of Proposed Rulemaking, 14 FCC Rcd. 11006 (1999); *see also* Letter to Chief, WTB, FCC from Acting Associate Director of the Office of Spectrum Management, Department of Commerce, National Telecommunications and Information Administration (January 5, 2000). Further, *see Service Rules for the 746-794 MHz Bands, and Revision to Part 27 of the Commission's Rules*, WT Docket No. 99-168, First Report and Order, 15 FCC Rcd. 476 (2000).

The power of a UWB signal interfering with a victim receiver can be found by starting with the radiated power of the UWB interfering signal within the victim receiver bandwidth. This signal is adjusted to account for the effects of the gain of the transmitting and receiving antennas and the propagation loss. Mathematically, this is expressed in the following equation:

$$I = P_{UWB} + G_T - L_P + G_R - L_R \quad (\text{Eq. 1})$$

where:

$I$  = interfering signal power level at receiver input (dBm)

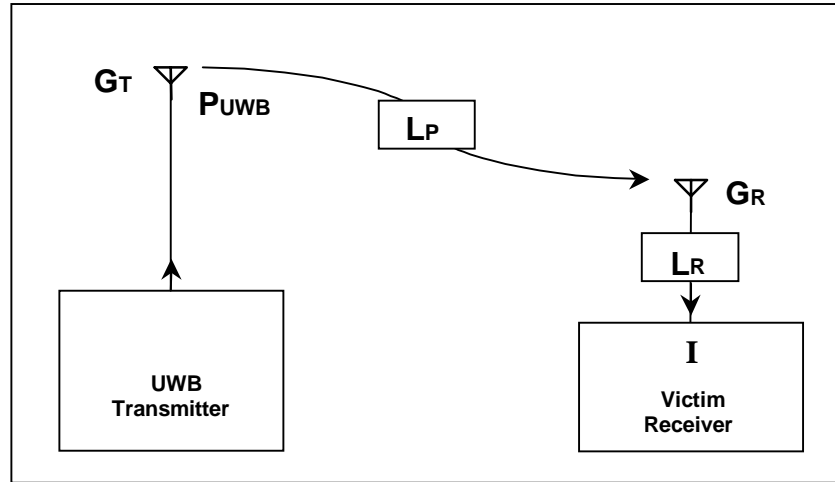
$P_{UWB}$  = radiated interfering signal power level of the UWB transmitter within the receiver bandwidth of the victim receiver (dBm)

$G_T$  = UWB transmitter antenna gain (dBi)

$L_P$  = propagation loss between the UWB transmitter and the victim receiver (dB)

$G_R$  = victim receiver antenna gain (dBi)

$L_R$  = cable/insertion loss of the victim receiver (dB)



**Figure 1 - Link Schematic**

Once an allowable interfering signal power level at the victim receiver is determined, other parameters in the Equation 1, above, can be estimated to obtain the required propagation loss, using the following expression:

$$L_P = P_{UWB} + G_T + G_R - L_R - I \quad (\text{Eq. 2})$$

This path loss can be converted into a distance using the expression for modified free space path loss between two antennas with gains relative to dipole antennas:

$$20\log(D_{sep}) = L_P - 20\log f - 28.15 - L_{adjust} \quad (\text{Eq. 3})$$

where:

$D_{sep}$  = distance separation between the UWB transmitter and the victim receiver (km)

$L_P$  = propagation loss between the UWB transmitter and the victim receiver (dB)

$f$  = frequency of the UWB transmitter (MHz)

$L_{adjust}$  = factor to account for differences from free space path loss<sup>11</sup>

### 1. UWB-to-Mobile Case

In this case, the victim receiver will not “hear” transmissions from its own base station because the desired signal is attenuated by path losses and because the receiver is proximate to a UWB transmitter. Even at its relatively low transmit level, the emissions from the UWB transmitters that are in the victim receiver’s passband can be large enough to disrupt communications.

The magnitude of the effect depends on a number of factors. First, it depends on the magnitude of the UWB emissions. If those emissions are large, they will

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<sup>11</sup> This term may be positive, indicating that the path loss is greater than free space path loss because of the effects of local “clutter.” It is also possible for this term to be negative, indicating that the path loss is less than that experienced in free space. This can occur when the signal from the transmitter reaches the receiver via multiple paths, *e.g.*, wall or floor reflections, and when the amplitudes of those multiple signals add coherently at the receiver.

more easily mask the desired signal. Second, it depends on the signal strength of the desired signal. If the signal is very weak, it is easier for the interferer to disrupt it. The only protection that the victim radio has from this interfering signal is geographical separation from the source, so that, due to path loss, the absolute level of the interfering signal at the victim receiver will be low enough to allow signals, *i.e.*, from the base station, to be received.

The practical result is that, in the area directly around the interfering transmitter, communications will be disrupted. At some distance away from the interfering transmitter, the communications path to the victim receiver will not be completely disrupted, though it may still be degraded. And at some distance beyond that, there will be no disruption or degradation. The size of the disrupted area is related to the desired signal's strength at the victim receiver, which means that the interference impact is greatest in areas where the desired signal is weakest at the victim receiver. These are areas which are either far from the victim system's base station, or areas in which the desired signal has been attenuated by, for example, terrain blockage, foliage, building penetration, etc. In short, interference effects will be greatest in areas of "fringe" coverage of the victim system.

Equations 1-3 can be used to understand the magnitude of this effect. For example, it can be assumed that an acceptable level of interference is one that will cause a 1 dB rise in the noise floor of the victim receiver.<sup>12</sup> A 1 dB rise in the noise floor will

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<sup>12</sup> See NTIA Comments, *supra*, at page 6. The NTIA analysis assumes an interference threshold of -134 dBm for a 6.25 kHz Public Safety receiver. This is equivalent to about a 1 dB increase in the noise floor.

be caused by a signal which comes into the receiver at 6 dB below the receiver noise floor.<sup>13</sup>

The Commission proposes to allow UWB devices to operate in accordance with the Part 15 Class B limits.<sup>14</sup> In Section 15.209, the general radiated emission limit for frequencies above 960 MHz is set at 500• V/m at a distance of 3 meters measured in a 1 MHz bandwidth.<sup>15</sup> This can be converted to an EIRP value for radiation from a dipole antenna by using the following equation:

$$P_{dBm} = 20\log(E_{\mu V/m}) - 75 - 20\log(f_{MHz}) \quad (\text{Eq. 4})$$

Equation 4 gives the relationship between the power received at a half-wave dipole antenna and a field strength of  $E$  in microvolts per meter for a frequency of  $f$  megahertz. Because the signal field strength is measured at a certain distance from the transmitter (in this case 3 meters), free space propagation is used to express the power measured at the plane of the transmitting antenna. Free space propagation between two dipole antennas is expressed in Equation 5:

$$L_{fs} = 20\log(f_{MHz}) + 20\log(r_{km}) + 28.1 \quad (\text{Eq. 5})$$

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<sup>13</sup> If the noise floor is denoted as  $f_{mW}$ , and the interference level is  $i_{mW}$ , the requirement of a 1 dB rise in the noise floor can be stated as  $10 \times \log_{10}(f+i) - 10 \times \log_{10}(f) = 1$  dB. Expressing  $i$  as a fraction of  $f$  so that  $i = f \times r$ , the expression can be reduced to  $\log_{10}(1+r) = 0.1$ . The solution for this expression is  $r = 0.26$ , which means that the interference level must be 0.26 times the noise floor in order to see a 1 dB total rise in the noise floor, and, expressed in decibels this factor is -5.85 dB.

<sup>14</sup> See *NPRM* at ¶18.

<sup>15</sup> 47 C.F.R. § 15.209(a).

Including the path loss from Equation (5) into the power measurement of Equation (4) allows conversion from the FCC's proposed Part 15 emission value into a power measurement, in dBm, into a dipole transmitting antenna.

$$P_{dBm} = 20 \log(E_{\mu V / m}) + 20 \log(r_{km}) - 46.9 \quad (\text{Eq. 6})$$

or

$$P_{dBm} = 20 \log(E_{\mu V / m}) + 20 \log(r_{km}) - 44.75$$

if an isotropic radiator is assumed. (An isotropic radiator has 2.15 dB less gain than a dipole.) With  $E = 500 \bullet \text{ V/m}$  and  $r = 0.003 \text{ km}$  (3 meters), at the Part 15 emission limit  $P_{UWB} = -41.25 \text{ dBm}$ , measured in a 1 MHz bandwidth by an isotropic antenna.

In order to estimate the interference impact, some performance characteristics of the generic victim receiver must be assumed; in this case a bandwidth of 25 kHz and a noise figure of 10 dB. (The receiver bandwidth is not really relevant to this analysis because the noise floor and UWB interference both scale with this parameter, leaving the final result unchanged. Assuming a bandwidth, however, facilitates working with example values.)

Using Equations 1-6 and the above parameters, the following link budget analysis unfolds:

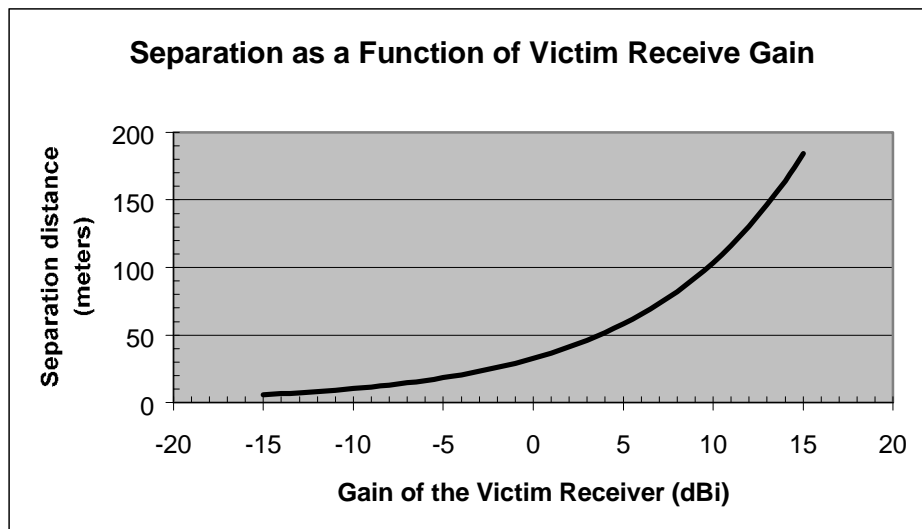
Parameter	Value
kT	-174 dBm/Hz
Victim Receiver Bandwidth (BW)	25 kHz (0.025 MHz)
Victim Receiver Noise Figure (NF)	10 dB
Victim Receiver Noise Floor = $kT + 10 \log (BW_{Hz}) + NF$	-120.02 dBm
Allowed Interference level (6 dB below the noise floor)	-126.02 dBm
UWB Interference in a 1 MHz bandwidth	-41.25 dBm
UWB Interference scaled to a 25 kHz bandwidth	-57.27 dBm
UWB transmitter gain ( $G_T$ )	0 dBi
Victim receiver gain ( $G_R$ )	-8 dBi
Victim receiver line loss ( $L_R$ )	0 dB
Path loss required to reach allowed UWB interference level in the 25 kHz bandwidth (Equation 2)	60.75 dB
Minimum required victim-to-UWB separation assuming free space path loss at 2 GHz (Equation 3)	13 meters

**Table 1 - Link Budget Analysis for UWB-into-Victim Mobile Interference**

This analysis shows that a victim receiver would need to be some 13 meters away from an UWB device transmitting in the victim receiver's band at the Part 15 limit in order avoid an increase in the receiver noise floor by more than 1 dB. The only parameters to which this analysis is sensitive are the victim receiver noise figure, the various antenna gains, and the propagation model. As noted, the analysis stays the same regardless of the victim receiver's bandwidth.

Because the Part 15 emission limits are determined by a radiated test, it is reasonable to assign a gain of 0 dBi to the UWB transmitter since the UWB interference

level has been defined to be at the Part 15 limits. However, the victim receive antenna is dependent upon the actual victim system and may vary widely. The value for antenna gain used (-8 dBi) is typical for a handheld cellular phone, but it is not representative of the values for car mounted antennas, antennas for fixed wireless systems, or wireless LAN systems. For fixed applications the receive antenna gains may, in fact, be positive (but directional) resulting in unacceptable interference from UWB devices at greater distances in the direction of maximum gain. The effect of different victim antenna gains on the interference distance is shown in Figure 2.



**Figure 2 - Separation as a Function of Victim Receive Gain**

A gain of +6 dBi (quite reasonable for a fixed system utilizing a patch antenna) would require as much as 65 meters of separation in order to keep the noise floor rise below 1 dB.

The above analysis demonstrates the rise in the noise floor experienced by a victim receiver at a certain separation from the interferer. It does not, however, discuss how often such a separation might be expected to occur, and how often the separation

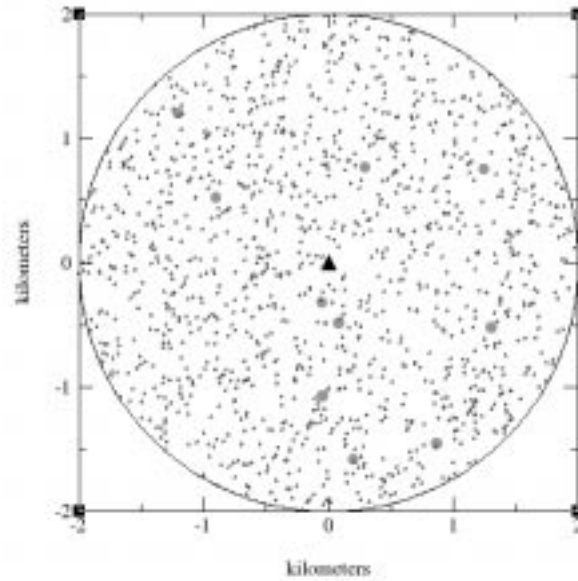
might be greater or less than this. It is possible to include these statistical effects through a Monte Carlo process.<sup>16</sup> Some results from such an analysis are shown here.

In Figure 3, a single configuration is shown of the basic structure of the model system evaluated in the Monte Carlo analysis. A single communications cell is shown with a radius of 2 kilometers. The victim system's base station (the solid triangle) is located at the center of the cell. Within that cell, 10 victim receivers (the solid circles) were placed at random locations, and UWB transmitters (the small stars) were randomly placed at a density of 100 UWB transmitters per square kilometer,<sup>17</sup> which, in this case, is 1256 UWB transmitters. Such a density is easily within the range of possibility were UWB devices to reach ubiquitous distribution for various services.

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<sup>16</sup> The Monte Carlo simulation process is a way of estimating the output statistics when the inputs to the process can be stated only in terms of probabilities. The input variables are randomly sampled, based on the statistical profile, and statistics for the output parameters are generated. In this case, for example, precise locations of the victim and interferer are not known, so those distributions are sampled and the resulting distributions of quantities like rise in the noise floor of the victim are generated.

<sup>17</sup> The population densities of a number of U.S. cities were examined to determine a reasonable value for this analysis. According to 1990 census data (<http://www.census.gov/population/www/censusdata/places.html>), the population density for St. Louis, MO is 2473.2/km<sup>2</sup>, for Washington, DC 3815.7/km<sup>2</sup>, and for Chicago, IL 4730.1/km<sup>2</sup>. Using a conservative density of 1000 people per square kilometer, a penetration rate of 30% for UWB technology with 30% of those devices being active at any one time yields an active device density of about 100 per square kilometer. The results of our analysis depend on this being a typical density of active devices. If the usage-density model for UWB devices were significantly higher, *e.g.*, were UWB handsets used as dynamic repeaters with substantially higher duty cycles, the results of our analysis would have to be adjusted accordingly.



**Figure 3 - Monte Carlo Simulation Configuration**

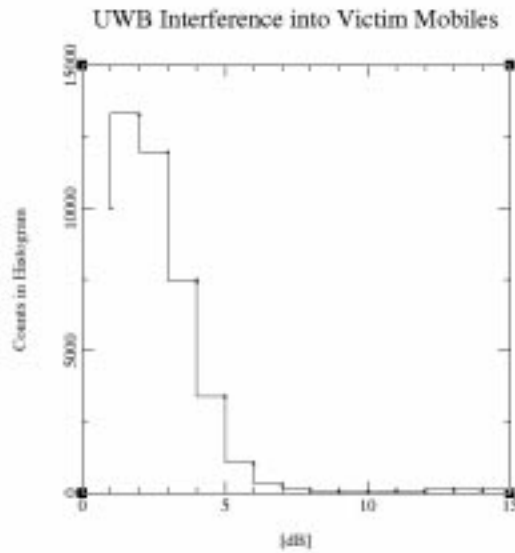
Interference from the UWB transmitters into the victim receivers was calculated for each victim receiver. The path loss was taken to be free space propagation for all devices within 100 meters of the victim receiver, and the Hata model for suburban propagation was applied to all others.<sup>18</sup>

One useful measurement from the Monte Carlo analysis is the number of UWB devices that have a significant impact on the victim receiver. In the Monte Carlo analysis, the interference from the UWB transmitter creating the most interference was listed first, the UWB transmitter creating the next most interference was listed second, and so on. In this way, it was possible to study how many transmitters had a significant impact on the victim receiver (the so-called aggregate interference problem.) Figure 4

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<sup>18</sup> M. Hata, "Empirical formula for propagation loss in land mobile radio services," IEEE Trans. On Vehicular Technology, Vol. VT-29, No. 3, Aug. 1980, pp. 317-325

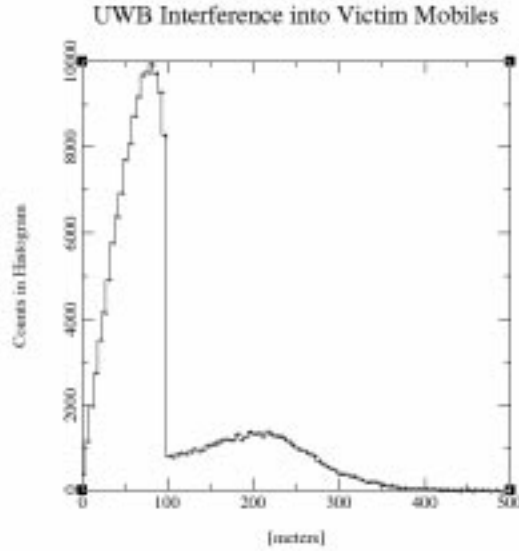
shows how many UWB units were required to make up 90% of the interference in the victim receiver.



**Figure 4 - Number of UWB Transmitters Creating 90% of the Interference**

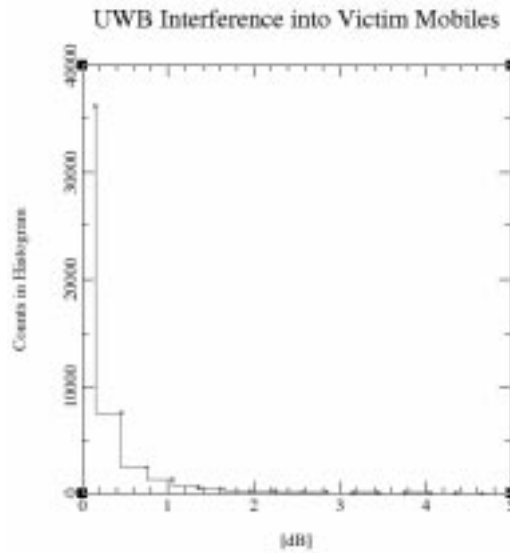
This figure illustrates that the vast majority of the time more than 90% of the interference is coming from the closest one to five UWB transmitters. Thus, the effect of aggregate interference (from the over 1000 UWB transmitters present in the simulation) is not as severe as the effect of the closest UWB transmitters.

The distance distribution from the victim receiver to each of the UWB transmitters that make up 90% of the interference is shown in Figure 5. The effect of the transition from free space propagation to Hata propagation at 100 meters is clearly evident in the distribution.



**Figure 5 - Distance to the 90% Interference Contributors**

The distribution of the resulting rise in the noise floor of the victim receivers is shown in Figure 6.



**Figure 6 - Rise in the Victim Noise Floor Due to UWB Interference**

The data from this Monte Carlo simulation can be used to check for consistency with the earlier interference analysis. Because 10 victim receivers and 1256

UWB transmitters were placed in each simulated event, and because 5000 events were simulated, there were a total of 50,000 victim receivers and 6,280,000 UWB transmitters. In the analysis, as illustrated in Figure 6, there were 46,780 victim receivers in which the noise floor was raised by 1 dB or less, and 3,220 receivers in which the noise floor rise exceeded 1 dB. That is, 6.4% of the events had an unacceptable noise floor rise. This number can be translated into an effective "noise rise" area around each UWB transmitter as follows:

$$\text{Total coverage area} = \pi r^2 = 12.56 \text{ km}^2$$

$$\text{Area per UWB transmitter} = 12.56 \text{ km}^2 / 1256 = 0.01 \text{ km}^2$$

$$\text{Noise rise area} = 0.01 \text{ km}^2 \times 0.064 = 0.00064 \text{ km}^2$$

This area of 0.00064 km<sup>2</sup> can be expressed as a circle with radius 14.3 meters, a value which matches quite well with the minimum UWB-to-victim separation of 13 meters found from the analysis above.

In summary, this analysis demonstrates that UWB transmitters within line-of-sight of a victim receiver will raise the noise floor of that receiver. On average, a zone with a radius exceeding 10 meters will exist around each UWB transmitter within which the noise floor will be degraded by more than 1 dB.

## **2. UWB-to-Base Station Case**

It is also possible to analyze the interference from UWB transmitters into victim base stations using the methodology applied to the UWB-to-mobile case. In the UWB-to-base station case, UWB transmitters deposit energy into the base station receiver of a wireless communications system. The resulting rise in the noise floor of the base station will influence its ability to receive weaker desired signals. Therefore, units

in fringe areas (such as those which are located indoors or those which are far from the base station) will not be able to establish an inbound link to the base station.

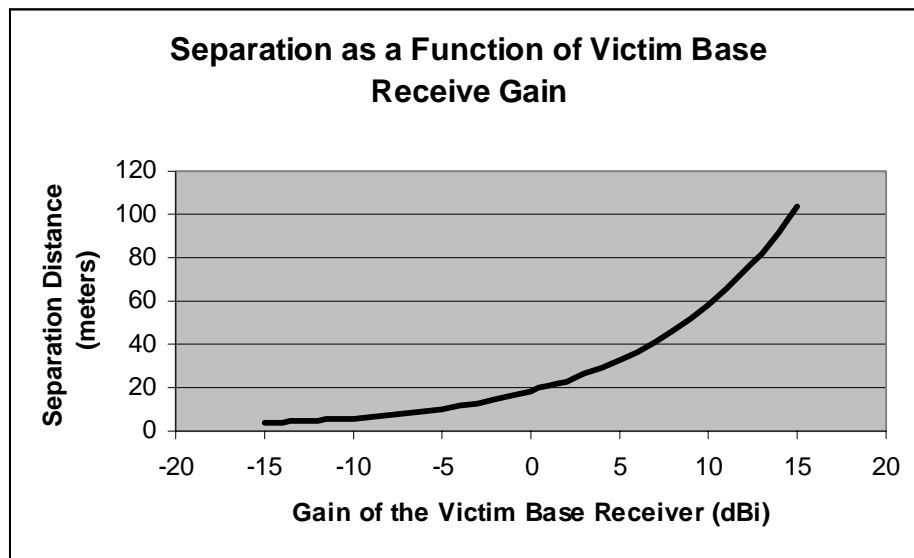
The same analysis used above for the UWB into mobile receiver case can be used for this case. The results are shown in Table 2, below:

Parameter	Value
kT	-174 dBm/Hz
Victim Receiver Bandwidth (BW)	25 kHz (0.025 MHz)
Victim Receiver Noise Figure (NF)	10 dB
Victim Receiver Noise Floor = $kT + 10\log(BW_{Hz}) + NF$	-120.02 dBm
Allowed Interference level (6 dB below the noise floor)	-126.02 dBm
UWB Interference in a 1 MHz bandwidth	-41.25 dBm
UWB Interference scaled to a 25 kHz bandwidth	-57.27 dBm
UWB transmitter gain ( $G_T$ )	0 dBi
Victim receiver gain ( $G_R$ )	12 dBi
Victim receiver line loss ( $L_R$ )	0 dB
Path loss required to reach allowed UWB interference level in the 25 kHz bandwidth (Equation 2)	80.75 dB
Minimum required victim-to-UWB separation assuming free space path loss at 2 GHz with 5 dB of "clutter" loss (Equation 3)	73 meters

**Table 2 - Link Budget Analysis for UWB-into-Victim Base Interference**

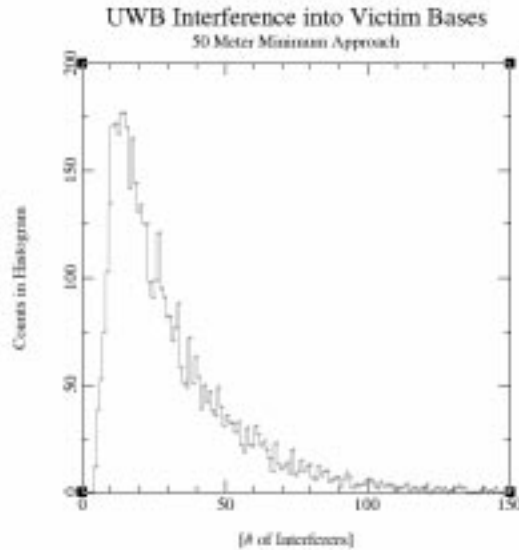
This analysis shows that a victim base station receiver would need to be some 70 meters away from a single UWB transmitter transmitting in the base station receive band at the Part 15 limit in order avoid an increase in the noise floor of more than

1 dB. The major difference between this analysis and the UWB-to-mobile receiver analysis is in the gain of the victim receiver. Base station antennas in a typical cellular system will feature such higher gain figures (12 dBi), so this result is not unexpected. However, it is physically difficult to approach a base station receiver, and base station antennas do not have a constant gain as a function of elevation. Both of these facts tend to mitigate this problem. Separation distance is shown as a function of the base station antenna gain in Figure 7.



**Figure 7 - Separation as a Function of Victim Base Receive Gain**

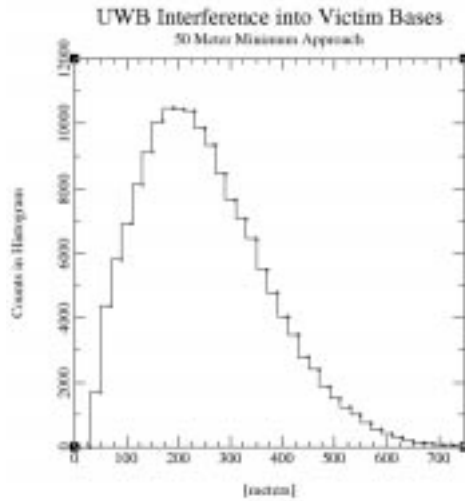
A Monte Carlo analysis of this effect was also performed, and some of the results are presented below. The same configuration as described above and illustrated in Figure 3 was used. In this analysis no UWB transmitter was allowed within 50 meters of the base station receiver.



**Figure 8 - Number of UWB Transmitters Creating 90% of the Interference**

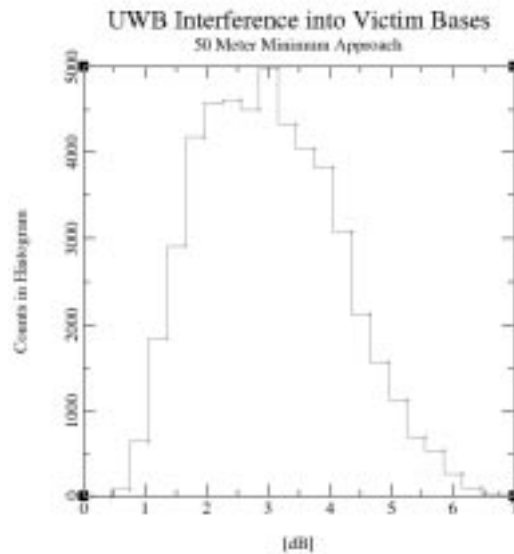
As Figure 8 shows, the interference situation for the base station is different than for the mobile stations. Because no unit is allowed within 50 meters, and because the propagation model used was the Hata model, a larger number of UWB transmitters is required to encompass 90% of the interference into the base station. In this example, the number of interfering units is typically between 10 and 100. Aggregate interference is more of a problem in this case than in the UWB-to-mobile case.

The distance from the base station to these 90% interference contributors is shown in Figure 9.



**Figure 9 - Distance to the 90% Interference Contributors**

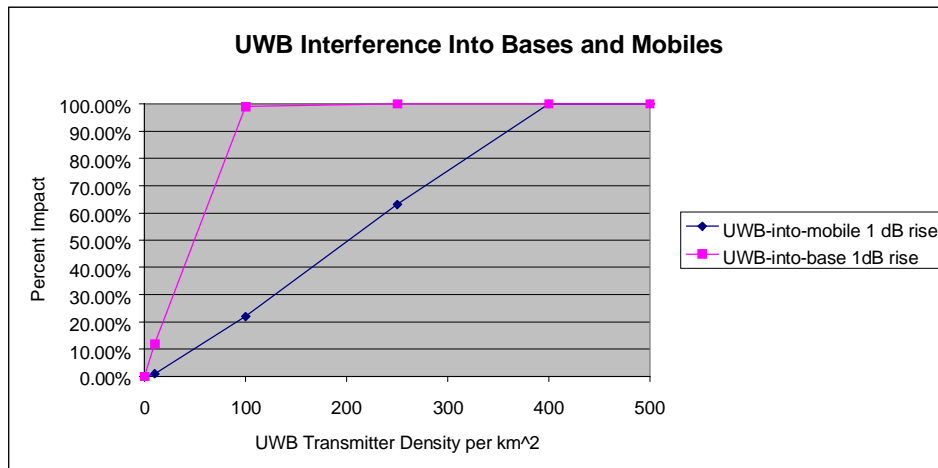
Though only units within about 70 meters of the base station cause a noise floor increase in excess of 1 dB, the cumulative effect of multiple units as far away as 600 meters results in comparable sensitivity degradation



**Figure 10 - Rise in Victim Noise Floor Due to UWB Interference**

As Figure 10 shows, the vast majority of the time (90% in this simulation), the increase in the base station noise floor will exceed 1 dB.

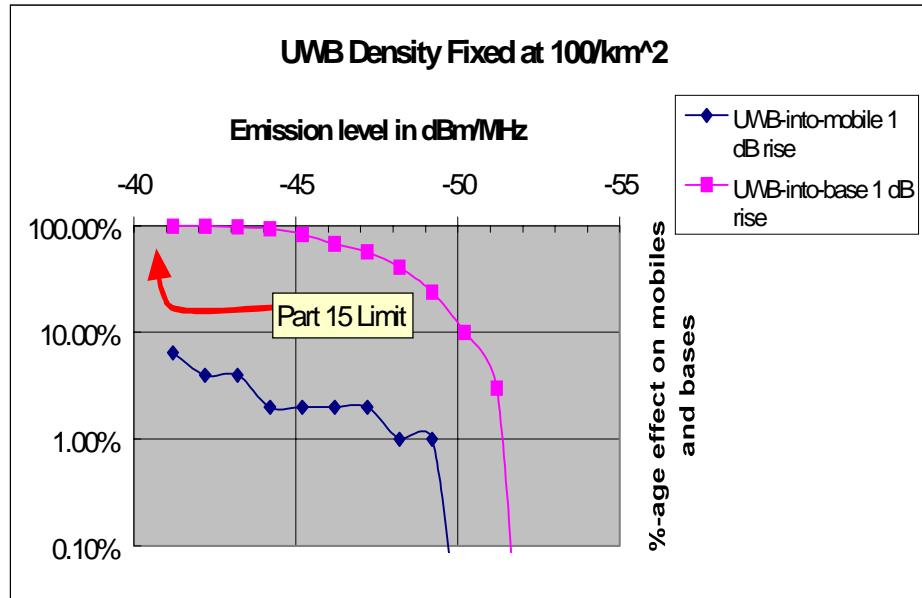
The Monte Carlo results presented so far were all based on a UWB transmitter density of 100 transmitters per square kilometer. A study of the impact of changing this density value on the overall interference probabilities is shown in Figure 11.



**Figure 11 - UWB Interference as a Function of UWB Transmitter Density**

This figure confirms what was expected: the ambient noise floor increases dramatically with the density of UWB transmitters.

It is also possible to study the effect of changing the UWB emission level. The above results are based on an emission level that is at the FCC's Part 15 limit. Figure 12 shows the effect of reducing this emission level for a UWB device density of 100 per square kilometer.



**Figure 12 - UWB Interference as a Function of UWB OOB Level**

As shown, the noise levels in the receivers, for mobile and base, no longer rise more than 1 dB when the emissions are reduced by 9 dB and 11 dB below the Part 15 limit, respectively.

Using a generic receiver analysis, it has been shown that transmissions at levels currently specified in Part 15 within the allocations of licensed spectrum users can degrade the noise floor of both victim mobile and base station receivers. While this effect is largely due to the nearest UWB transmitters, particularly in the mobile station interference case, the probability that such interference will occur is strongly dependent on the density of UWB transmitters in the environment. Using a model with a reasonable density of UWB transmitters, a reduction of the permissible emissions by 12 dB below

the Part 15 limits virtually eliminates the probability of noise floor degradation by more than 1 dB.<sup>19</sup>

#### **B. Comparison of Proposed Emissions to Current Standards**

In the above analysis, Motorola has determined an appropriate emission level for UWB devices. This level was established by requiring that the victim receiver noise floor be degraded by less than 1 dB. Another way to approach this problem is by examining the self-interference that wireless system designers typically allow, *i.e.*, the level of emission that a wireless transmitter deposits into its own receive band is a good indication of the level of interference which can be considered acceptable.

Appropriate and reasonable out-of-band-emission limits can be determined by comparing the proposed UWB limits with emissions limits for conventional cellular subscriber units, as shown in Table 3 below.

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<sup>19</sup> This result is dependent on the system parameters and device densities used in the simulation and will not hold for all scenarios.

SYSTEM	General Limit	Subscriber Unit Rx Band Limit	Source
UWB	-57	<b>-57</b>	FCC Part 15
GSM900	-50	-85	GSM 05.05
DCS1800	-55	-77	GSM 05.05
TDMA (800&1900 MHz)	-49	-81	IS137
IDEN	-51	-81	iDEN Spec

**Table 3 - Comparison of Subscriber Unit Out-of-Band Emissions Limits  
(Power Measured in 25 kHz BW at Antenna Connector (in dBm))**

The emissions limits are given in terms of noise power in a 25 kHz bandwidth at the antenna connector. For the cellular systems, two emission limits are shown. First, a general limit figure that applies to most of the spectrum outside the transmit band; and, second, the subscriber unit receive band (shaded). The latter figure is important because it determines how close similar subscriber units can operate without interfering with each other. Wideband noise produced by one unit can increase the effective noise floor of nearby receiver units, degrading the quality of their links or even causing dropped calls. The relevant operating scenario is where two or more persons in close proximity are attempting to communicate at the same time. Examples include public places like airports, sporting venues, or shopping malls.

For most of the listed cellular systems, the subscriber receive band specification is considerably more stringent than the general limit. This indicates the degree to which technical standards bodies and equipment manufacturers are aware of and responsive to the subscriber-to-subscriber interference scenario. More importantly, it

can be seen that while the Part 15 specification is roughly in line with the general out-of-band emission figures, it falls short of the typical receiver band specifications by 20 dB to 28 dB.

One way to assess the impact of this shortfall is to look again at the sensitivity degradation, or noise floor increase, suffered by a subscriber unit due to another unit operating a close distance away, *e.g.*, 3 meters. Conversely, for a given noise floor degradation of 1 dB, the separation distance can be determined. Analyses from both perspectives have been carried out for UWB and conventional systems. The results are summarized in Table 4. The following assumptions were made for the calculations: 10 dB victim receiver noise figure; -3 dBi victim receiver antenna gain; -3 dBi interfering transmitter antenna gain; and free space propagation. For the UWB case, the victim receiver is assumed to be a cellular subscriber unit operating at 1900 MHz.

<b>SYSTEM</b>	<b>Noise Floor Increase (in dB) with 3 meter Separation</b>	<b>Separation Distance (in meters) for 1 dB Noise Floor Increase</b>
<b>UWB</b>	9.7	17.3
<b>GSM900</b>	0.3	1.5
<b>DCS1800</b>	0.4	1.9
<b>TDMA-800 MHz</b>	0.8	2.7
<b>TDMA-1900 MHz</b>	0.2	1.1
<b>iDEN-900 MHz</b>	0.6	2.4

**Table 4 - Noise Floor Degradations Due to Subscriber-to-Subscriber Interference**

These results provide more concrete evidence that the proposed Part 15 emissions limit are inadequate as a communications system design requirement. Conventional systems have been designed to allow several users to operate their wireless

handsets at fairly close quarters with minimal mutual interference. One might argue that this is true only for users in the same system and users in different systems are afforded less protection based on the general emissions limit. However, due to the proximity or shared status of bands for these systems, the *inter*-system interference performance is generally comparable to the *intra*-system performance. The characteristics of conventional circuit techniques help in this regard: a filter designed to reduce emissions in a system's own receiver band will tend to protect adjacent bands as well.

In contrast, a UWB device transmitting at the proposed Part 15 limit could cause substantial degradation to other services, or to another UWB radio. Indeed, a 9.7 dB noise floor increase translates to a downlink range reduction of 47%, or a coverage area reduction of 72%, assuming co-channel reuse interference is not the limiting factor.<sup>20</sup>

### **C. Conclusions From the U.K. Radiocommunications Agency Analysis**

In a recent study by the U.K. Radiocommunications Agency, the cumulative interference from UWB sources was investigated using an analytical interference model.<sup>21</sup> In rural areas, the interference on a noise-limited cellular system or a CDMA system was found to be negligible, i.e., less than 1 dB degradation, for UWB

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<sup>20</sup> This assumes an  $r^{-3.5}$  propagation model. In this regard, it should also be noted that the current out-of-band emissions limits (*e.g.*, Section 15.247 of the Rules) for Bluetooth and 802.11 wireless LAN devices operating in the 2.4 GHz ISM band are somewhat more lax than the general Section 15.109 limit. Hence, such devices could cause even more interference to cellular phones than UWB, assuming they operate near the specified limits. However, these devices likely operate at substantially lower out-of-band emission levels due to the rolloff properties of conventional filters and antennas.

<sup>21</sup> See An Investigation into the Potential Impact of Ultra-Wideband Transmission Systems, Radiocommunications Agency Report RA0699/TDOC/99/002, February 2000..

source densities of less than 50 per square km, assuming that the UWB transmitter powers had the unintentional radiator emission levels specified in Part 15 of the Rules. Similarly for urban areas, the interference to a CDMA system was found to be insignificant for UWB source densities of 100 per square km. For an interference limited FDMA/TDMA cellular system, the maximum density of UWB sources in an urban area that caused negligible interference was found to be up to 2500 sources per km.

The density of UWB devices in urban and rural areas was able to be even higher before the interference affected the operation of GPS receivers. Up to five UWB devices could be used in a typically residential home before a TV receiver's performance was degraded. This number is likely to be higher in practice due to the low antenna gain of a TV antenna in the direction of the UWB devices. Further, 150 UWB devices within a 100m x 100m area inside a large single-story building were found to inflict negligible interference on a noise limited receiver inside the building. Also, published theoretical models indicate that the interference from terrestrial UWB devices is harmless to navigational devices in aircraft.<sup>22</sup>

Still, interference problems from UWB sources were found to occur if the victim receiver was in close range and in LOS (line-of-sight) of at least one UWB device. Moreover, even if a victim receiver was not close to a UWB device, the cumulative interference due to a proliferation of UWB devices could not be ignored. A UWB micro-cellular system or wireless local loop system in an urban area could degrade the performance of cellular receivers in all street areas, because a cellular receiver is always

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<sup>22</sup> All of the above results assumed that the UWB transmitter powers were at the current Part 15 unintentional radiator emission levels. *See NPRM* at ¶18.

within close range and in LOS of a UWB device. These scenarios are likely and therefore could not be ignored. This analysis concluded that it would be appropriate to set the power spectral density limits to at least 10 dB below the current Part 15 limits.

## **VI. THE BULK OF THE EVIDENCE POINTS TOWARDS STRICTER PART 15 EMISSION LIMITS BY AT LEAST 12 dB**

### **A. The Rationale Proposed By the Commission For Different Emissions Specifications Above and Below 2 GHz is Not Clear**

In its *NPRM*, the Commission proposes that UWB systems be permitted to operate above 2 GHz with no additional restrictions beyond those currently imposed by Part 15 of the Rules.<sup>23</sup> For spectrum below 2 GHz, however, the situation is different. The Commission offers a number of suggestions, including

- UWB devices not be permitted to operate below 2 GHz;<sup>24</sup>
- UWB devices be permitted to operate below 2 GHz at emission levels 12 dB below the Part 15 Rules.<sup>25</sup>

The rationale for the 2 GHz cutoff is explained in the *NPRM* as being based on a desire to protect the high concentration of wireless services below 2 GHz from harmful interference.<sup>26</sup> This is a worthy goal, but it is not clear to Motorola why a cutoff

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<sup>23</sup> See *NPRM* at ¶27.

<sup>24</sup> *Id.* at ¶30.

<sup>25</sup> *Id.* at ¶39.

<sup>26</sup> *NPRM* at ¶ 28. "We have a number of concerns about generally permitting the operation of UWB devices in the region of the spectrum below approximately 2 GHz. This is perhaps the most heavily occupied region of the spectrum and is used for public safety, aeronautical and maritime navigation and communications, AM, FM and TV broadcasting, private and commercial mobile communications, medical telemetry, amateur communications, and GPS operations. We note that 41 of the 64 restricted frequency bands are at or below 2 GHz, not counting the TV broadcast bands. We are

at 2 GHz is appropriate. Indeed, there are many wireless services that need to be protected from harmful interference above 2 GHz. A partial list is shown in Table 5.

<b>Frequency Band</b>	<b>Service</b>
150 MHz	Land Mobile Radio
450-512 MHz	Land Mobile Radio
746-806 MHz	Public Safety and Cellular
806-894 MHz	Public Safety, Land Mobile Radio, SMR, and Cellular
896-901 MHz and 935-940 MHz	Specialized Mobile Radio
1559-1610 MHz	GPS (Global Positioning System)
1710-1850 MHz	DCS 1800 overseas. One of the bands identified for 3G expansion at WRC 2000.
1850-1990 MHz	PCS
2110-2150 MHz	Allocated for commercial purposes in the US. Potential 3G spectrum.
2150-2160 MHz	The MDS spectrum, using in the conjunction with the 2.5 GHz MMDS spectrum.
2305-2320 and 2345-2360 MHz	The WCS band.
2500-2690 MHz	MMDS bands in the US. One of the bands identified for 3G expansion at WRC 2000.
3650-3700 MHz	A major band for WLL around the world.
4940-4990 MHz	The new General Wireless Communications Service.
5850-5925 MHz	Dedicated Short Range Communication devices.
25-42 GHz	LMDS and LMCS bands in various parts of the spectrum in various countries.

**Table 5 - Example List of Commercial Wireless Spectrum Bands**

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particularly concerned about the impact of any potential interference to the GPS band at 1559-1610 MHz."

As can be seen from this table, wireless services exist throughout the spectrum.

Choosing a cutoff frequency below which UWB emissions should be prohibited or reduced is, therefore, difficult to justify.

**B. The Commission's Proposal to Require UWB Emissions to be 12 dB Below the Part 15 Limits Conforms With Motorola's Analyses**

As discussed above, the technical evidence supports a requirement that UWB emissions be reduced on the order of 12 dB below the Part 15 limit.

- Figure 12 indicates that a reduction in the limit of 12 dB will reduce both UWB-to-mobile and UWB-to-base station interference cases to less than 1% probability of occurrence
- A comparison with out-of-band emission limits from other technologies indicates that a reduction of at least 20 dB would be necessary to bring UWB into parity with other communications technologies
- The study from the UK Radiocommunications Agency concludes that an emission limit set at 10 dB below the FCC limits would be appropriate.

**C. Recommendation: Set the Out-of-Band Limits at 12 dB Below Current Part 15 Limits For All Frequencies**

In its *NPRM*, the Commission proposed that for all frequencies below 2 GHz the emissions from UWB devices be limited to 12 dB below current Part 15 limits.<sup>27</sup> Based on the above analyses and the need to protect communications systems which span the spectrum, Motorola proposes that this limitation be extended to all frequency bands.

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<sup>27</sup> See *NPRM* at ¶39.

## **VII. CONCLUSION**

In order to assess UWB's interference potential, Motorola has analyzed UWB transmissions in a variety of typical radio environments. Several methods of assessing interference potential are considered, and the likely effects on generic receivers are carefully examined. Based on these detailed analyses, Motorola concludes that the Commission's tentative decision to require that UWB emissions below 2 GHz be attenuated by at least 12 dB below the general Part 15 emission limits is both appropriate and necessary. In addition, Motorola's analyses show that the same protection level is warranted for UWB devices above 2 GHz. This 12 dB reduction strikes a reasonable balance between protecting existing and future radio services and encouraging technological innovation. Motorola also believes that this reduction in the frequency

domain must be complemented with appropriate limitations in the time domain, to properly reflect the potential interference impact of UWB devices operating in the TDMA mode.

Respectfully submitted,

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